MICROSCOPIC SIMULATION WITH AIMSUN FOR THE ASSESSMENT OF INCIDENT MANAGEMENT STRATEGIES

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ABSTRACT

PRIME (Prediction of Congestion and Incidents in Real Time, for Intelligent Incident Management and Emergency Traffic Management) was a project of the 5ht Framework Program of the European Union which objectives were to develop: methods for estimating incident probability in real-time, which can activate traffic management strategies to reduce the likelihood of incidents, improved systems and algorithms for detecting incidents, an improved integration of incident verification to increase the reliability of incident management, and the integration of aspects of motorway and urban-network incident management strategies to increase the effectiveness of incident and traffic management strategies in urban / interurban areas. This paper deals with the use of microscopic simulation to assess the potential impacts of the incident management strategies. A methodological scheme on how to use simulation to achieve these objectives is presented and the experimental plan for the test site in Barcelona is described and the preliminary testing results are presented.

INTRODUCTION

PRIME builds on recent achievements in the management of incidents and road emergencies in EU projects (1), and enhances weak links in the incident and road emergency management chain. The objectives of PRIME have been to: Develop Methods for **estimating incident probability** in real-time, which can activate traffic management strategies to reduce the likelihood of incidents; Develop improved systems and algorithms for **detecting incidents** (2), and explore the Integration of aspects of motorway and urban-network incident management strategies to increase the effectiveness of incident and traffic management strategies in urban / interurban areas. The project has developed models of incident probability to estimate the likelihood of occurrence of incidents in real time (3). Estimation is based on geometric, weather and traffic characteristics. The operator can use the output from the models to support traffic management decisions that seek to reduce the probability of incident occurrence. Reducing this probability is expected to benefit the system, even if the immediate benefit may not always be visible to the drivers. An incident is defined as any non-recurrent event, which causes reduction of roadway capacity or increase of risk to drivers. Incident or congestion prediction comprises the estimation of the potential for occurrence of incidents or congestion in real time. Congestion in this context concerns incident related emergence or growth of queues, also denoted as ‘non-recurrent congestion’ or ‘incident related congestion’. Incident detection is the activity of monitoring traffic with the aim of (automatically) recognising the occurrence of an incident. This can be done either directly by spotting the vehicles involved in the incident or indirectly by analysis of deviant behaviour of other traffic that is reacting to the incident.

METHODOLOGY FOR TESTING THE SYSTEM BY SIMULATION

The conceptual approach to simulation testing is depicted in the logic diagram of Figure 1: A calibrated AIMSUN (4), model (Box 1) of the test site emulates the traffic conditions on the scenario to be tested.

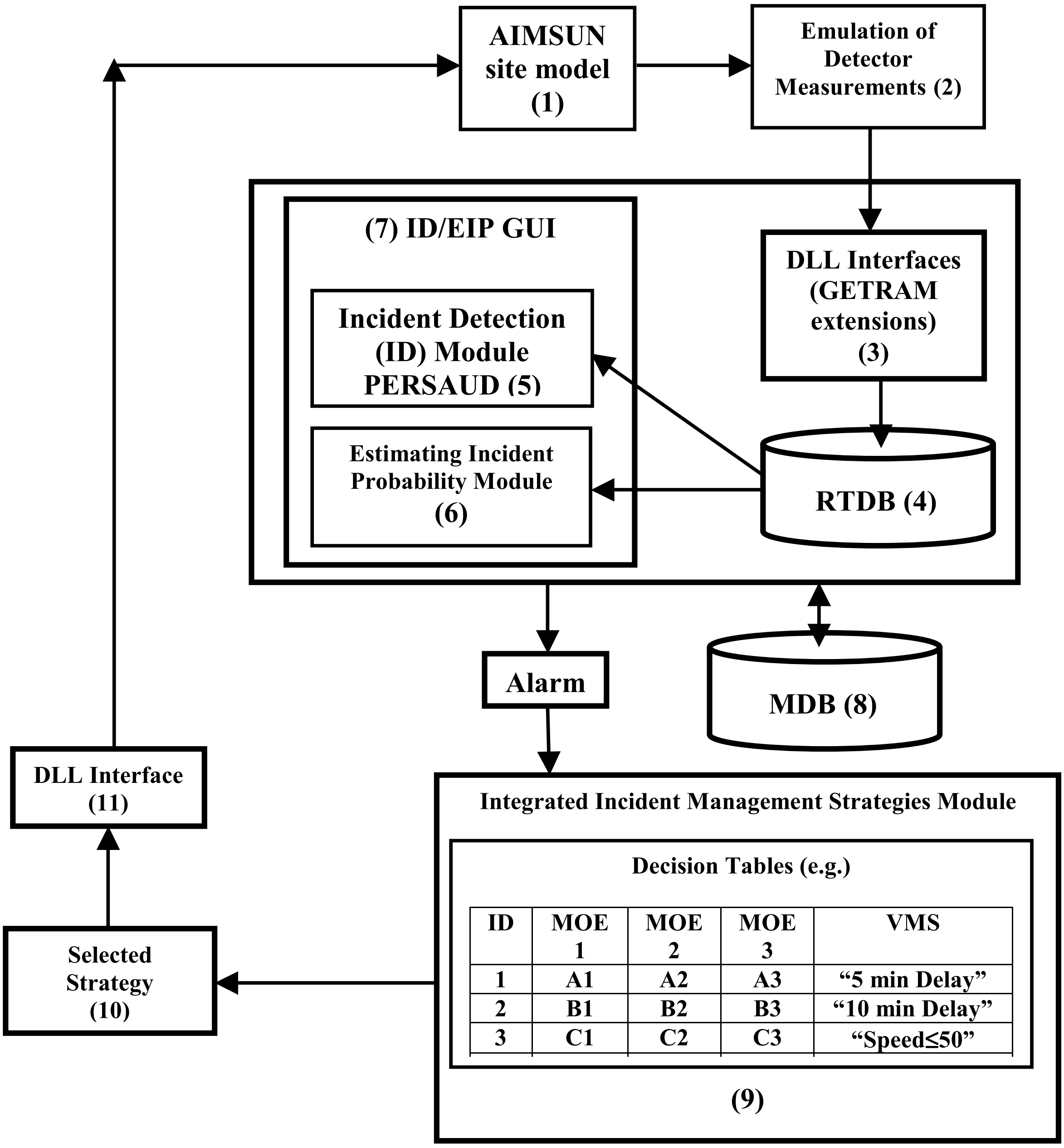

Figure 1. Conceptual structure of the PRIME testing process based on microscopic simulation with AIMSUN

Running the calibrated model generates traffic measurements (flow, occupancy, speed and traffic composition, Box 2) emulating those that would be provided by the available on-street detection systems. These data produced by the model for various simulated detectors is stored in the PRIME Real Time Data Base RTDB (Box 4) by means of an ad hoc interface built with the DLL GETRAM library of functions available in AIMSUN, an API to interface external applications (Box 3). The Incident Detection/Estimation of Incident Probability Graphic User Interface (ID/EIP GUI) (Box 7) activates the Incident Detection Module (An adapted version of Persaud's algorithm in this case, Box 5) and Estimating Incident Probability Module (A purposely designed and implemented Hierarchical Logit Model, Box 6) through the corresponding dialogues with the operator. When incidents are predicted/detected, the corresponding information is stored in the PRIME Main Data Base MDB (Box 8) and the Integrated Incident Management Strategies Module is alerted which chooses traffic control plans and/or information dissemination plans according to the severity of the conditions encountered following the site ad hoc decision process (Box 9). The module has been designed as a Decision Support System that on basis to detected/predicted incident, and the identified current traffic conditions recommends the type of management actions (information through VMS, dynamic speed control, re-routings based on VMS, ramp metering at on ramps, etc.). The selected strategy (Box 10) can then be fed back into the simulator in terms of VMS messages which are designed to divert certain proportions of drivers or control plans which will alter priority at traffic signals. A site specific DLL GETRAM interface (Box 11) feeds the parameters of the strategy back into AIMSUN. The effects of these strategies can then be monitored and their impacts evaluated. The decision tables which make up the IIMS module have been developed off-line at the site through a series of simulation experiments. These form a dictionary of traffic control plans and information dissemination plans, derived by running various incident scenarios on each specific set of key links in the network defining the critical areas.

INTEGRATED INCIDENT MANAGEMENT STRATEGIES

There is a general agreement on the idea that as soon as an incident is detected an early intervention could greatly help in alleviating the congestion effects originated by the incident and possibly prevent secondary accidents.

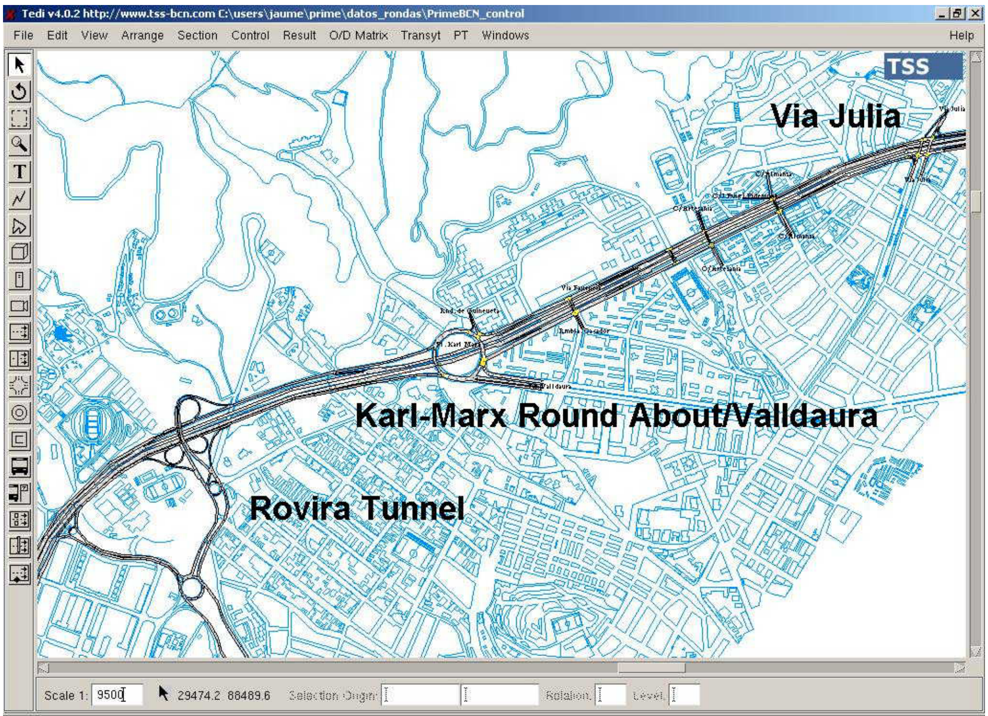

Figure 2: AIMSUN model of the Problem Area for PRIME simulation testing of Incident Management Strategies.

The potential management strategies greatly depend on the network structure, (possibilities of traffic diversion, interactions between the motorway and the adjacent surface roads, or urban streets in the case of an urban motorway), conditions (i.e. saturated or free flows) and available devices (Variable Message Panels, ramp metering, etc.).The urban motorway between the “Nus de Trinitat” and “Nus Diagonal” in Barcelona is heavily congested the main part of the day and in the selected Problem Area at the site there are three main interchange nodes, Via Julia, Karl-Marx Roundabout and Tunel de la Rovira, with strong interactions with the urban network. The reasons for selecting this Problem Area for testing purposes have been namely: the sensitivity to traffic conditions due to the interactions, the equipment of the area enabling the implementation of management strategies, and the quality of the collected data. The implementation of a management strategy could lead to strong conflicts unless it is tested and its potential impacts evaluated a priori. This is specially true in the selected problem area where for example queues at on-ramps of the urban motorway could potentially interfere with signalized intersections close to the interchange nodes, or where a substantial increase in the flows at an off ramp could also create a congestion in the adjacent urban street. PRIME project offered a suitable laboratory framework to off-line testing by simulation the potential impacts of these management strategies. The AIMSUN micro simulation model of this Problem Area is depicted in Figure 2.

FORMAL DEFINITION OF THE INCIDENT MANAGEMENT STRATEGIES

The incident alarm provides the primary input to the IIM module, which then retrieves from the RTDB and the Incident _Detected the complementary information: The formal description of the required information when the network has been coded in terms of the GETRAM representation fro the AIMSUN model is the following (Figure 3): Section identity (i.e. Section ID #n), Incident location: section(s) between two adjacent detectors, Severity of the incident according to the specified code, Estimation of the duration (if possible). A traffic management strategy also requires the currently available traffic data for the affected section: Traffic data from detection stations j and j+1 in figure 5, traffic data at the Entry and Exit ramps. And the available traffic data in the potentially affected related sub-network, when the spill back of queues at on-ramps can interfere with the urban network, or when an increase of exit flows at exit ramps can collapse the adjacent urban intersections.

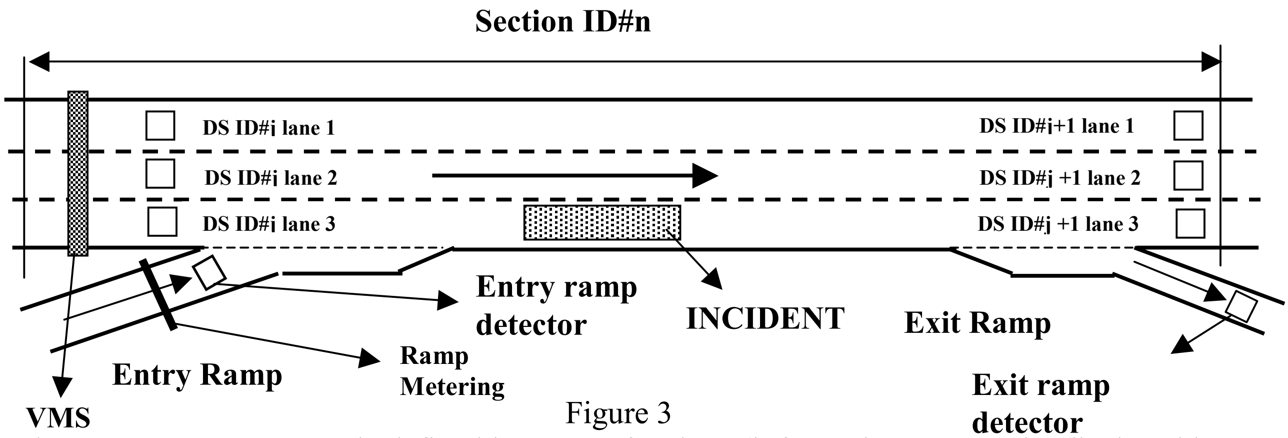

Figure 3

The management strategy is defined in terms of actions (information to motorist displayed by Variable Message panels (VMS), Variable Speed Limits, or Ramp metering at specific on-ramps, this requires the identification of the available control and management devices, and the specification of the available actions, i.e.: VMS at section ID #n: library of messages that can be displayed, Ramp metering device at Entry ramp ID #k: library of available ramp metering policies at ramp ID #k (i.e. flow metering, adaptive metering, etc.). The management strategies are the formally described in terms of rules function of the available actions and their combinations: Warnings at the VMS, Route recommendations, Speed control, Ramp metering, others. The Integrated Incident response consists on a decision support process based on the pre-assessment by simulation of the pre-defined strategies on a set of scenarios defined after the reconstruction of well identified incident situations.

THE SCENARIO AND THE EXPERIMENTAL OFF-LINE TESTING PLAN IN BARCELONA

The calibrated simulation model of the site has been the engine of the prototype used to design potential scenarios for testing and evaluating by simulation the performance of the management strategies. The design factors have been the available management strategies at the selected Problem Area in the site. At the selected Problem Area of Barcelona's site there are available three types of strategies (single factors), and their combinations (combined factors): Information and route recommendations using the Variable Message Panels, Speed control on the main sections using the Variable Speed Signs, Access control based on ramp metering strategies at the equipped entry ramps. The selected Problem Area has (Figure 4): 3 Off-ramps direction Llobregat (identified as LS2, LS3 and LS4 respectively in Figure 4); 4-On-ramps direction Llobregat (identified respectively as LE1, LE2, LE3 and LE4 in Figure 4); 3 On-ramp direction Besos (coded BE4, BE3 and BE2 in Figure 4); 3 Off-ramp direction Besos (coded BS4, BS3 and BS2 in Figure 4);1 VMS panel direction Llobregat (between LS1 and LS2 in Figure 4); 1 VMS panel direction Besos (between BE5 and BS4 in Figure 4) The On-ramps in both directions are equipped with lights that could implement ramp metering strategies. The strong interaction between the Ring Road and the urban network trough these service roads makes that any strategy implemented on the Ring Road could potentially have a strong impact on the adjacent urban network, limiting in that way its actions, i.e. a ramp metering at On-Ramp 2, direction Llobregat (LS2), could potentially create queues spilling back to the service road and blocking the access to the Roundabout in "Plaza Karl Marx".

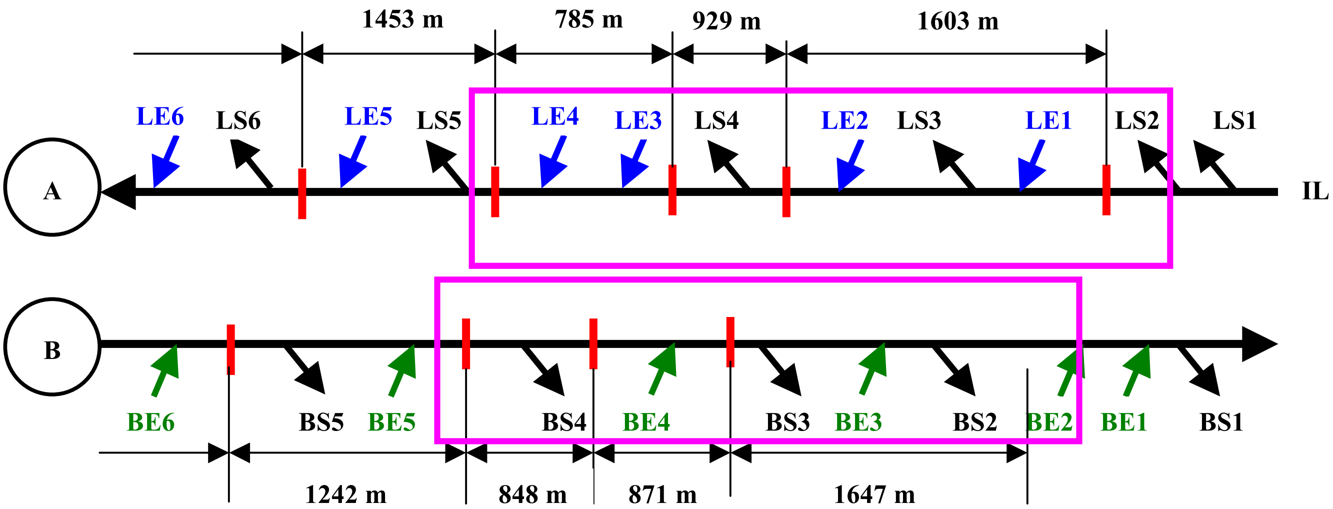

Figure 4: Schematic diagram of equipment available in the Problem Area

This implies that the simulation experiments to define and evaluate off-line a strategy including such potential action should take into account limitations in the allowed queue lengths. The strategy defined for the problem area in both directions has the following components: Display information and warning messages on the VMS informing on the presence of congestion, incidents, etc., Variable speed limits compulsory, Alternate the information messages with warnings, Rerouting information (try to force the use of specific off-ramps leading to alternative routes), Ramp metering at On-rams upstream of the incident /

congestion location. Two experimental scenarios have been implemented for the Problem Area of the simulation model: the do nothing scenario (current situation) and the scenario in which the strategy is triggered when an incident is detected, or a selected set of MOE's (i.e. level of service, average speed) falls below a predefined threshold. The scenarios have been assessed for the traffic conditions used to calibrate the basic simulation model. The simulated incidents have been the replication of the observed incidents. The main objective of the simulation experiments has been: Estimate the potential benefits of the single factors and the combination of factors with respect to the do-nothing scenario, and estimate the effects of a timely identification of incidents in combination with the design factors, both in terms of a selected set of MOE's. The strategies considered in the design belong to two categories: Strategies based on traffic diversion from the motorway to the arterial and/or using ramp metering to alleviate the congestion in the motorway when the arterial is not congested; and the same when the arterial is congested. The strategy then integrates the arterial conditions reducing the diversion from the arterial and taking into account in the ramp metering the length of the queues at the affected entrance ramps.

SIMULATION RESULTS

Three sets of tests have been performed using three Data Sets from the Historical data Base of recorded incidents and related traffic data:
A. Tests for strategies based on diverting from the motorway to the arterial and/or on applying ramp metering at the affected on-ramps
1st Test: For the first test the simulation scenario consisted of the full implementation of the conceptual diagram depicted in figure 1. A subset of well identified incidents, the 1st Data Set and two alternative versions, S2 (Scenario with a strategy based only on warnings (inducing an assumed 10% diversion from the motorway to the arterial) and dropping the speed limits from 80 to 60 Km/h.) and S3 (Scenario with all the above described components and specific diversion recommendations (inducing an assumed 15% diversion), dropping speed limits from 80 to 60 Km/h, and imposing ramp metering at the affected on-ramps), of the scenario have been simulated and compared against the do nothing scenario, S1. **2nd and 3rd Tests**: The second third tests have been based on a refined version of Persaud, allowing a better detection, using data and incidents from the 2nd and 3rd Data Sets respectively, and comparing the scenario that uses strategy S3, the most promising strategy, against the do nothing scenario, S1.
B. Additional tests with the 3rd Data Set, changing the diversion percentages and speed limits, analyzing in detail the main motorway sections and the related arterial conditions in the Problem Area, between "Nus de Trinitat" and "Tunel de la Rovira", to identify the conflicting situations caused in the arterial by the diversion from the motorway or the ramp queues.
4th Test: Refined Persaud, do nothing scenario S1, strategy S3 with 10% diversion and 60Km/h speed limit; **5th Test:** Refined Persaud, do nothing scenario S1, strategy S3 with 15% diversion and 60Km/h speed limit; **6th Test**: Refined Persaud, do nothing scenario S1, strategy S3 with 10% diversion and 50Km/h speed limit; **7th Test**: Refined Persaud, do nothing scenario S1, strategy S3 with 15% diversion and 50Km/h speed limit
C. Replication of tests 4th to 7th integrating the strategy S3 for the motorway with two strategies for the arterial consisting on: A1: reducing the diversion from the motorway by a factor depending on the flow on the arterial, deactivating the ramp metering when on-ramp queues are of critical length (i.e. reach the limits of the on-ramp) and forcing vehicles on the arterial to reroute, and A2: As A1 and adapting timings on the affected signalized intersection on the arterial to accommodate the flows. **8th Test:** As in test 4th with strategy A1; **9th Test:** As in test 5th with strategy A1; **10th Test:** As in test 4th with strategy A2; **11th Test:** As in test

5th with strategy A2. The analysis in this case has been restricted to the entrance ramp before "Plaza de Karl Marx" where have been identified the main problems resulting form the spillback of the entrance queues into the arterial as a consequence of strategy S3. This corresponds to a paradigmatic situation to test the integration of motorway and arterial strategies.

1st test

Measure Of Effectiveness	Definition	Values S1	Values S2 (* 1)	Values S3 (* 2)
IIMS MOE 1	Delays in Vehicle-Hours over the entire modelled network.	21.44	18.56 -15.51%	23.78 +9.84%
IIMS MOE 2 –	Total travel time in Vehicle-Hours over the entire modelled network.	36.56	38.63 +5.35%	35.27 -3.65%
IIMS MOE 3 –	Total travel distance in Vehicle-Kilometres over the entire modelled network.	388885	401728 +3.2%	367582 -5.80%

2nd and 3rd Tests

Measure Of Effectiveness	Definition	Values S1	Values S3 (* 2)	Values S3 (* 3)
IIMS MOE 1 –	Delays in Vehicle-Hours over the entire modelled network.	295008	291619 -1.14%	289473 -1.87%
IIMS MOE 2 –	Total travel time in Vehicle-Hours over the entire modelled network.	460552	426824 -7.34%	424875 -7.74%
IIMS MOE 3 –	Total travel distance in Vehicle-Kilometres over the entire modelled network.	4454072	4441016 -0.3%	4440927 -0.3%
IIMS MOE 4	MOE4: Journey Time (hr)	0.2682	0.2606 -2.85%	0.2587 -3.54%

4th, 5th, 6th and 7th tests

Measure Of Effectiveness	Definition	Values S1	Test 4th	Test 5th	Test 6th	Test 7th
IIMS MOE 1.1	Delays in Vehicle-Hours over the main motorway section Túnel Rovira-Trinitat., Problem Area	570.97	**364.27 -36.2%**	**382.79 -32.9%**	**360.41 -35.7%**	**447.07 -20.9%**
IIMS MOE 1.2	Delays in Vehicle-Hours over the main motorway section Trinitat -Túnel Rovira., Problem Area	515.33	**315.38 -38.8%**	**361.75 -29.8%**	**325.62 -36.8%**	**404.608 -21.4%**
IIMS MOE 1.3	Delays in Vehicle-Hours over the arterial Túnel Rovira-Trinitat., Problem Area	273.67	374.40 +36.8%	305.3 +11.5%	312.91 +14.3%	297.275 +8.62%
IIMS MOE 1.4	Delays in Vehicle-Hours over the arterial Trinitat -Túnel Rovira, Problem Area	199.72	261.625 +30.8%	236.57 +18.4%	232.17 +16.24	207.15 +3.72%
IIMS MOE 2.1	Total travel time in Vehicle-Hours over the main motorway section Túnel Rovira-Trinitat., Problem Area.	2031	**1470 -27.6%**	**1487 -26.7%**	**1469 -27.6%**	**1549 -23.7%**
IIMS MOE 2.2	Total travel time in Vehicle-Hours over the main motorway section Trinitat -Túnel Rovira, Problem Area.	1988	**1466 -26.2%**	**1568 -21.1%**	**1513 -23.9%**	**1883 -5.28%**
IIMS MOE 2.3	Total travel time in Vehicle-Hours over the arterialTúnel Rovira-Trinitat., Problem Area	629.21	739.40 +17.5%	734.21 +16.7%	760.9 +20.9%	696.78 +9.69%
IIMS MOE 2.4	Total travel time in Vehicle-Hours over arterial Trinitat -Túnel Rovira, Problem Area.	458.06	558.15 +21.8%	570.7 +24.4%	503 +9.81%	474.58 +3.48%
IIMS MOE 3.1	Total travel distance in Vehicle-Kilometres Hours over the main motorway section Túnel Rovira-Trinitat., Problem Area..	45935.3	**43274.2 -5.79%**	**41485.8 -9.68%**	**43044.8 -6.29%**	**39646.9 -13.7%**
IIMS MOE 3.2	Total travel distance in Vehicle-Kilometres Hours over the main motorway section Trinitat -Túnel Rovira, Problem Area..	53810.4	**39570.6 -24.4%**	**36838.5 -31.5%**	**38954.3 -27.6%**	**34479.9 -35.9%**

Measure Of Effectiveness	Definition	Values S1	Test 4th	Test 5th	Test 6th	Test 7th
IIMS MOE 3.3	Total travel distance in Vehicle-Kilometres Hours over the arterial Túnel Rovira-Trinitat., Problem Area.	8994.7	**8921.2 -0.81%**	**8866.3 -1.42%**	**8967.5 -0.30%**	**8818.3 -1.96%**
IIMS MOE 3.4	Total travel distance in Vehicle-Kilometres Hours over the arterial Trinitat -Túnel Rovira-., Problem Area..	11347.0	11877.4 +4.46%	11788.2 +3.88%	11846.1 +4.39%	11530.3 +1.61%
IIMS MOE 4.1	Journey Time (hr) over the main motorway section Túnel Rovira-Trinitat., Problem Area.	0.1775	**0.1375 -22.3%**	**0.145 - 18.3%**	**0.1380 -22.2%**	**0.1647 -7.21%**
IIMS MOE 4.2	Journey Time (hr) over the main motorway section Trinitat -Túnel Rovira, Problem Area.	0.1955	**0.14 -28.3%**	**0.1605 -17.9%**	**0.1472 -24.7%**	**0.1869 -8.13%**
IIMS MOE 4.3	Journey Time (hr) over the arterial Túnel Rovira-Trinitat., Problem Area.	0.3194	0.3486 +9.14%	0.3472 +14.3%	0.3555 +11.3%	0.3405 +6.60%
IIMS MOE 4.4	Journey Time (hr) over the arterial Trinitat - Túnel Rovira-., Problem Area	0.1869	0.2091 +11.8%	0.2141 +13.6%	0.1958 +4.76%	0.2172 +16.2%

8th, 9th, 10th and 11th tests

Measure Of Effectiveness	Definition	Values S1	Test 8th	Test 9th	Test 10th	Test 11th
IIMS MOE 1.2	Delays in Vehicle-Hours over the main motorway section Trinitat -Túnel Rovira., Problem Area	515.33	**324.10 -37.1%**	**346.336 -32.8%**	**447.15 -13.2%**	**347.25 -32.6%**
IIMS MOE 1.4	Delays in Vehicle-Hours over the arterial Trinitat -Túnel Rovira, Problem Area	199.72	**187.83 -5.95%**	**168.50 -15.6%**	**165.21 -17.2%**	**175.24 -12.2%**
IIMS MOE 2.2	Total travel time in Vehicle-Hours over the main motorway section Trinitat -Túnel Rovira, Problem Area.	1988	**1526 -23.2%**	**1585 -20.2%**	**1828 -8.04%**	**1605 -19.2%**
IIMS MOE 2.4	Total travel time in Vehicle-Hours over the arterial Trinitat-Túnel Rovira, Problem Area.	458.06	**440.2 -3.89%**	**456.33 -0.37%**	**449.2 -1.93%**	**457.13 -0.20%**
IIMS MOE 3.2	Total travel distance in Vehicle-Kilometres Hours over the main motorway section Trinitat -Túnel Rovira, Problem Area..	53810.4	**36785.8 -31.6%**	**35760 -33.5%**	**34763.8 -35.4%**	**34652.7 -35.6**
IIMS MOE 3.4	Total travel distance in Vehicle-Kilometres Hours over the arterial Trinitat -Túnel Rovira, Problem Area..	11347.0	11935.4 +5.18%	12273.4 +8.16%	12111 +6.73%	11893.0 +4.81%
IIMS MOE 4.2	Journey Time (hr) over the main motorway section Trinitat -Túnel Rovira, Problem Area.	0.1955	**0.1541 -21.1%**	**0.1652 -15.6%**	**0.1811 -7.36%**	0.1958 +0.15%
IIMS MOE 4.4	Journey Time (hr) over the arterial Trinitat - Túnel Rovira-., Problem Area	0.1869	0.1983 +6.09%	0.1969 +5.35%	0.1877 +0.42%	0.2047 +9.52%

COMMENTS ON THE SIMULATION RESULTS

(1) The initial experiments show an improvement that reduces the overall delay. Although there is reduction in travel times, consequence of the reduction in delays, the increase in total travel times is due to the increase in the total number of vehicles, as can be seen in the increase in MOE3. The simulated scenario assumes that drivers accept the warnings and look for alternative routes when congestions or incidents occur downstream, and follow the speed limit indications. (2) This scenario requires further analysis. The expected improvements are not achieved, and in fact the conditions deteriorate with respect to the do nothing scenario. A preliminary analysis indicates that metering create queues in some on ramps that strongly interact with the urban network blocking some critical intersections. The implemented strategy has been of auto-adaptive type, trying to keep the flows in the main section under certain threshold values. That means that more complex metering strategies should be taken into account i.e. metering that also uses queue lengths at on-ramps as control variable. (3) The use of global MOE's to evaluate complex scenarios as the ones proposed for the IIMS in

PRIME could be misleading. This becomes clear when analysing the structure of the proposed PRIME site, and realizing the strong interaction between the motorway and the urban network. In particular, ramp capacity design frequently allows queues at entrance or exit ramps to interfere with signalised intersections, as in the case of the figure 5.

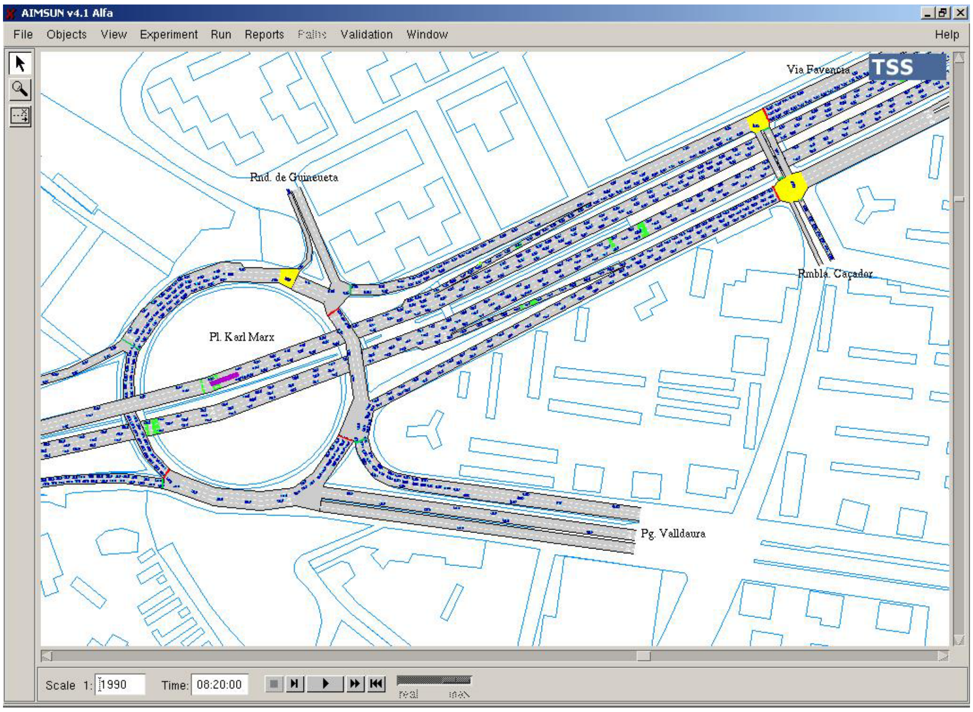

Figure 5. Reproducing an observed incident by simulation to analyze its impacts

In this case the simulation model allows a detailed analysis of the effects of the ramp metering based strategy with results provided separately for (a) the main sections of the motorway and (b) the entrance and exit ramps. The figure 6 depicts graphically an example of such analysis comparing the scenarios with and without responsive ramp metering activated by the detection of an incident, and showing clearly how flow conditions on the main sections improve substantially when ramp metering is applied (higher flow, lower density and higher speed, resulting in shorter travel times). The gains on the main sections can be counterbalanced by the losses at entrance/exit ramps, namely when there is interference with signalised intersections, resulting in a worse global MOE. The set of tests 4th to 7th has been devoted to the detailed analysis of the proposed strategies for the motorway in the conflicting part of the site selected as Problem Area. The analysis has made the distinction between the main section of the motorway and the arterial. In green have been highlighted the situation of improvement and in red when the results are worse. In general as expected the selected strategy S3 combining diversion from the motorway to the arterial improves the conditions in the motorway and deteriorates the conditions in the arterial. The study has made the distinction between those cases in which the worsening in the arterial is not critical from those in which is critical. These last situations are the ones described in the above paragraphs an illustrated with the above figure. Tests 8th to 11th have analysed the effects of integrating the motorway strategy S3 with the two proposed arterial strategies A1 and A2. As the table for tests 8th to 11th shows the integrated strategies provide better results. The combination of S3 with A1 seems to be the most successful. The performance of the off-line tests done by simulation have demonstrated the validity of the proposed methodology to assess and evaluate the impacts of the integrated management strategies prior to their implementation. The methodological platform whose logical structure was depicted in figure 1 has proven to be a valid simulation laboratory to integrate the various PRIME components and test scenarios that integrate management strategies for the motorway with strategies accounting for traffic conditions on the arterial. The results of the tests prove the potential of an early intervention and the risks of a strategy that does not take into account the complex interactions arising in a urban/interurban context as the case of the site in Barcelona. This is the main consequence that can be drawn for the tests. As the analysis of the test performance highlights, although the overall MOE's show certain global improvements, some of the strategies can have undesirable side effect in the adjacent urban network. The detailed analysis of the network affected by the congestion and/or the incidents in tests 8th to 11th has enabled to distinguish the circumstances showing the benefits of the integration of the strategies diverting from the motorway when take into account the traffic conditions on the arterial. A caveat learned from the test concerns the impact of the rerouting strategies, as far as there is no yet a valid behavioural model accounting properly for driver's reactions to the VMS information. In the simulated scenarios a conservative 10-15% has been used based on the experience of the experts from the Municipality of Barcelona.

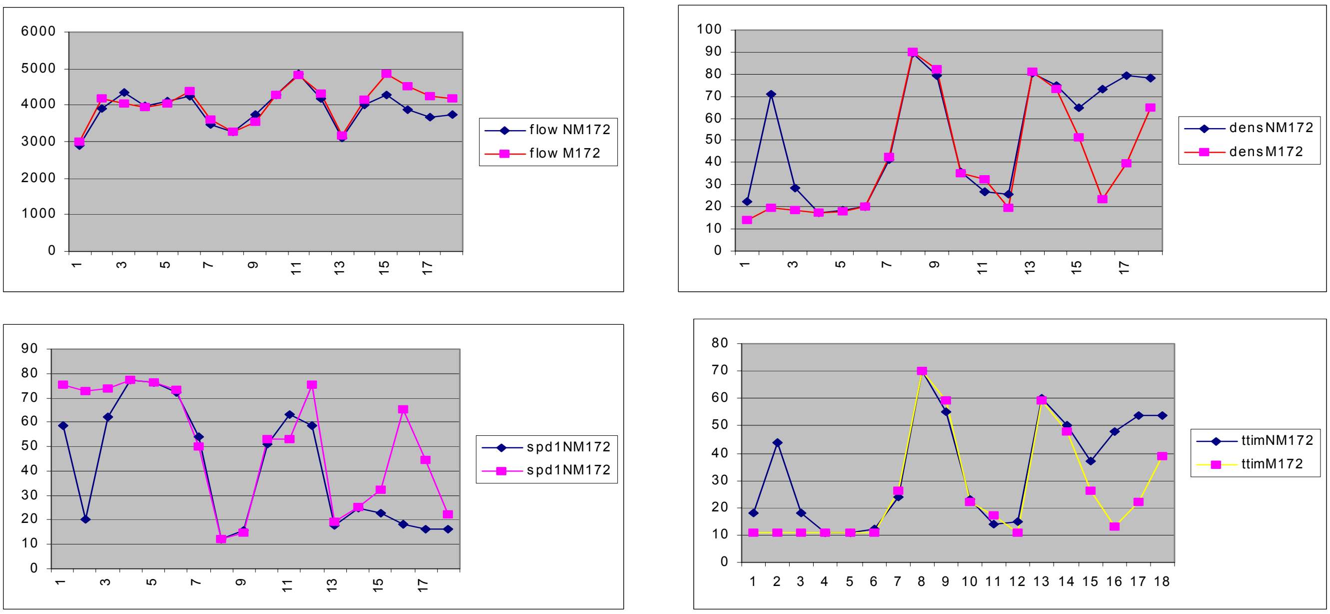

Figure 6. Details of the scenario analysis by simulation

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